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Research Article

Timing of Surgical Intervention and its Impact on Short-term Outcomes in Pediatric Hydrocephalus

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Abstract: Background: Hydrocephalus is a common pediatric neurosurgical condition. Timely surgical intervention is critical to prevent permanent neurological damage. Available research highlights the importance of optimal surgical timing. However, global data is limited, and local populations remain understudied.

Objective: To determine the impact of timing of surgical intervention on short-term postoperative outcomes in pediatric patients with hydrocephalus.

Materials and Methods: This retrospective observational study was conducted at the Pediatric Neurosurgery Department of the Children's Hospital and the Institute of Child Health, Multan, from January 2024 to March 2025. From the hospital record, data of 83 children aged 1 month to 12 years diagnosed with hydrocephalus and who underwent surgical intervention were analyzed using non-probability consecutive sampling. Children were categorized into early (≤7 days) and delayed (>7 days) intervention groups based on timing from diagnosis to surgery. Short-term outcomes like post-intervention complications, length of hospital stay, readmission, and mortality, were evaluated. Data analysis was performed using SPSS version 26.0. Descriptive and inferential statistics were applied, taking $p<0.05$ as statistically significant.

Result: Of the 87 patients, 48 (55.2%) were female. The median age was 5.42 (IQR: 3.00–8.67) years. Early intervention was performed in 47 (54.0%) and delayed in 40 (46.0%) patients. Enlarged head (46.8% vs. 25.0%, p=0.036) and poor feeding (55.3% vs. 32.5%, p=0.033) were more common in early group, while seizures were more prevalent in delayed group (6.4% vs. 25.0%, p=0.015). Median hospital stay was significantly shorter in early group (5.00 vs. 8.00 days, $p<0.001$). Readmission was significantly lower in early group (4.3% vs. 17.5%, p=0.043). Although shunt malfunction, infection, and day-30 mortality were lower in early group, differences were not statistically significant.

Conclusion: Early surgical intervention in pediatric hydrocephalus was significantly associated with shorter hospitalization and relatively lower early readmission rates, and potentially associated with fewer complications and mortality.

Keywords: Children, hydrocephalus, mortality, readmission, seizures, Etiology.

INTRODUCTION

Hydrocephalus is a common pediatric neurosurgical condition resulting from an imbalance between the production and absorption of cerebrospinal fluid (CSF), leading to progressive ventricular dilatation and raised intracranial pressure [1, 2]. Hydrocephalus affects 1 to 2 in every 1,000 live births, making it a significant contributor to pediatric neurosurgical workload. Worldwide, deaths associated with pediatric hydrocephalus are considerable with a 21.3% one-year mortality rate among treated patients [3].

Timely surgical intervention is critical to prevent permanent neurological damage [4]. However, the optimal timing of surgery and its effect on short-term outcomes remain a matter of clinical importance and variability, especially in resource-limited settings where delayed access to care may impact outcomes [5]. In low- and middle-income countries, delayed presentation and limited access to pediatric neurosurgical care are common [6-8].

Pediatric hydrocephalus can present in infancy or early childhood and arises due to a variety of etiologies, including congenital malformations, intraventricular hemorrhage, central nervous system infections, and tumors [9-11]. The standard treatment involves surgical CSF diversion techniques such as ventriculoperitoneal (VP) shunting or endoscopic third ventriculostomy (ETV) [12, 13]. Studies suggest that up to 40-50% of VP shunt procedures may require revision within the first year due to complications, with timing playing a potential role [13, 14]. Delay in surgical intervention has been associated with complications

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such as progressive cerebral atrophy, visual impairment, seizures, and developmental delays [15, 16]. In contrast, performing surgery too early in unstable or under weight infants can heighten the risk of complications like shunt failure or infection. Additionally, hydrocephalus cases caused by infection or intraventricular hemorrhage (IVH) often have worse short-term outcomes, particularly if treatment is delayed [17].

Available research highlights the importance of optimal surgical timing in improving outcomes for pediatric hydrocephalus patients. However, global data is limited, and local populations, particularly in South Punjab, remain understudied. This study aims to investigate the impact of the surgical timing on short term postoperative outcomes in pediatric hydrocephalus patients, by determining the effects of early versus delayed intervention, we can refine existing knowledge and inform treatment protocols, ultimately enhancing neurosurgical decision-making for children with hydrocephalus.

MATERIALS AND METHODS

This retrospective observational study was conducted at the Pediatric Neurosurgery Department of Children's Hospital and Institute of Child Health, Multan, Pakistan, spanning from January 2024 to March 2025. Approval from the ethical review committee was obtained (letter number: 777, Dated: April 10, 2025). Sample selection was done using a non-probability consecutive sampling technique. A sample size of 83 was calculated considering the shorter-term mortality in pediatric hydrocephalus as 12% [18], with 95% confidence level and 7% margin of error. The inclusion criteria were infants of any gender aged 1 month to 12 years diagnosed with hydrocephalus and undergoing surgical intervention. Exclusion criteria were those children who previously went through neurosurgical interventions, hydrocephalus secondary to unresected tumors, or those with significant systemic comorbidities affecting surgical timing. Hydrocephalus was diagnosed based on clinical symptoms (such as increased head circumference, vomiting, irritability, delayed milestones, and visual disturbances) and confirmed via neuroimaging (cranial ultrasound, CT scan, or MRI) showing ventriculomegaly.

From the hospital record, demographic details, etiology, clinical presentation and imaging findings were recorded. Children were categorized based on the timing of surgery from the onset of symptoms or diagnosis. Those who underwent surgery within 7 days of diagnosis were considered to have early intervention. Delayed intervention was named if the surgery was performed after 7 days of diagnosis. Different surgical procedures like ventriculoperitoneal (VP) shunt, endoscopic third ventriculostomy (ETV), external ventricular drain (EVD), or other (as appropriate), which were opted for treating the study infants, were documented along with the relevant intraoperative details. Short-term postoperative outcomes were evaluated in the form of shunt malfunction, defined as the recurrence of symptoms or imaging evidence of non-functioning shunt requiring revision, shunt infection based on the presence of fever, wound site infection, positive CSF culture, length of hospital stay, readmission, and mortality (defined as death within 30 days of surgery). Data about post-operative outcomes was noted up to 30 days post-operatively. The relationship between age at surgery and early clinical outcomes was evaluated.

STATISTICAL ANALYSIS

Data were analyzed using "IBM-SPSS Statistics" version 26.0. Descriptive statistics such as means and standard deviations (SD) or median and interquartile range (IQR) were used for continuous variables like age at diagnosis, and weight. Frequencies and percentages were reported for categorical variables, which included etiology of hydrocephalus, clinical presentation, imaging findings, surgical procedures, and short-term postoperative outcomes. The chi-square test or Fisher's exact test was used to compare categorical variables between early and delayed groups. A p-value <0.05 was considered statistically significant.

RESULT

In a total of 87 children, 48 (55.2%) were female, and 39 (44.8%) male. The median age was 5.42 (3.00-8.67) years. Among these, 47 (54.0%) underwent early surgical intervention, while 40 (46.0%) underwent delayed intervention. No statistically significant difference was observed in gender distribution between the early and delayed groups (p=0.687). Age stratification showed that children aged ≤1 year were more often operated on early, although this was not statistically significant (p=0.118). Imaging findings, including aqueductal stenosis (21.2% vs. 25.0%), intraventricular hemorrhage (14.9% vs. 10.0%), posterior fossa cyst (17.0% vs. 20.0%), tumor (10.6% vs. 15.0%), ventriculomegaly (2.8% vs. 15.0%), and other findings (23.4% vs. 15.0%) were statistically similarly distributed (p=0.872). Enlarged head was significantly more common among children who underwent early surgery (46.8% vs. 25.0%; p=0.036), while seizures were significantly more prevalent in the delayed surgery group (6.4% vs. 25.0%; p=0.015). Poor feeding was also significantly more frequent in early intervention cases (55.3% vs. 32.5%; p=0.033). Other symptoms such as vomiting (p=0.371), irritability (p=0.461), visual disturbances (p=0.361), and developmental delay (p=0.095) did not show significant differences. Etiologies of hydrocephalus were similarly distributed across groups (p=0.337). Table **1** is showing comparison of demographical and clinical characteristics with respect to timing of surgery.

The median duration of hospital stay was 5.00 (4.00-7.00) days in early surgery versus 8.00 (6.25-9.75) days in delayed surgery children (p<0.001) and the details are shown in Fig.(**1**).

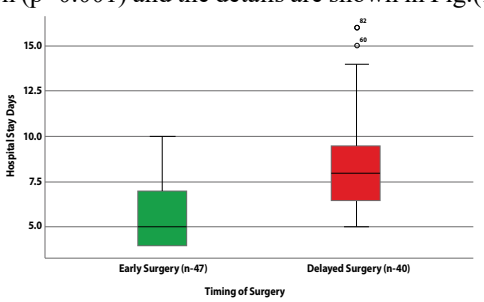

Fig. (1). Comparison of Duration of Hospitalization (n=87).

Table 1. Comparison of Demographical and Clinical Characteristics with Respect to Timing of Surgery (n=87).

Characteristics		Timing of Surgery		P-value
		Early (n=47)	Delayed (n=40)	
Gender	Male	22 (46.8%)	17 (42.5%)	0.687
	Female	25 (53.2%)	23 (57.5%)	
Age (years)	≤1	7 (14.9%)	1 (2.5%)	0.118
	>1 to 5	15 (31.9%)	17 (42.5%)	
	>5 to 12	25 (53.2%)	22 (55.0%)	
Imaging findings	Aqueductal steonosis	10 (21.2%)	10 (25.0%)	0.872
	Intraventricular hemorrhage	7 (14.9%)	4 (10.0%)	
	Posterior fossa cyst	8 (17.0%)	8 (20.0%)	
	Tumor	5 (10.6%)	6 (15.0%)	
	Ventriculomegaly	6 (12.8%)	6 (15.0%)	
	Others	11 (23.4%)	6 (15.0%)	
Presenting features/ symptoms	Enlarged head	22 (46.8%)	10 (25.0%)	0.036
	Vomiting	19 (40.0%)	20 (50.0%)	0.371
	Irratibility	13 (27.7%)	14 (35.0%)	0.461
	Seizures	3 (6.4%)	10 (25.0%)	0.015
	Visual disturbances	7 (14.9%)	9 (22.5%)	0.361
	Developmental delay	11 (23.4%)	16 (40.0%)	0.095
	Poor feeding	26 (55.3%)	13 (32.5%)	0.033
Etiology	Congenital	10 (21.3%)	6 (15.0%)	0.337
	Idiopathic	7 (14.9%)	8 (20.0%)	
	Post-infectious	4 (8.5%)	5 (12.5%)	
	Post intravencular hemorrhage	8 (17.0%)	5 (12.5%)	
	Spinal dysraphism	12 (25.5%)	5 (12.5%)	
	Tumor-related	6 (12.8%)	11 (27.5%)	
Surgery type	VP Shunt	29 (61.7%)	22 (55.0%)	0.547
	ETV	16 (34.0%)	14 (35.0%)	
	EVD	2 (4.3%)	4 (10.0%)	

Shunt malfunction was reported in 3 (6.4%) children in early surgery group versus 7 (17.5%) in delayed surgery (p=0.105). Shunt infection was observed in 3 (6.4%) children in early versus 5 (12.5%) in delayed surgery group (p=0.325). Readmission was required by 2 (4.3%) children in early versus 7 (17.5%) in delayed surgery group (p=0.043). Day-30 mortality was noticed in 1 (2.1%) child in early versus 3 (7.5%) in delayed surgery group (p=0.233). Comparison of short-term outcomes with respect ot timing of surgery is shown in Fig.(**2**).

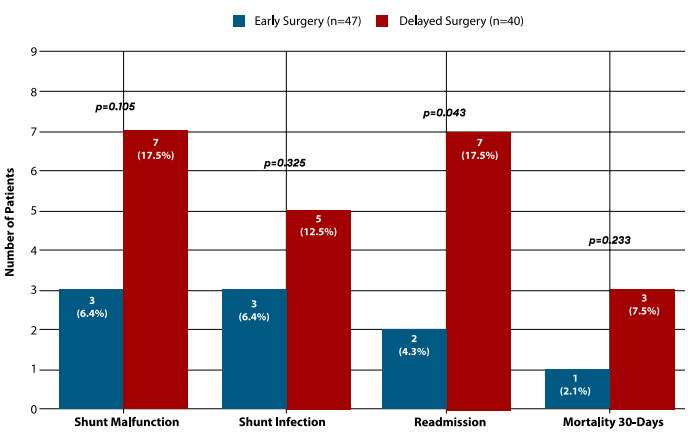

Fig. (2) Impact of Timing of Surgery on Short-Term Outcomes (n=87).

DISCUSSION

Readmission within 30 days was significantly higher in the delayed intervention group (17.5%) compared to the early surgery group (4.3%, p=0.043), suggesting that timing may influence the stability of early postoperative recovery. Readmissions in pediatric hydrocephalus are often linked to complications such as shunt malfunction, infection, or persistent symptoms of raised intracranial pressure. As observed in the current study, shunt malfunction and infections, although not significantly different, were numerically higher in the delayed group. This supports the notion that surgical delay may allow for further progression of the underlying pathology, increasing the complexity of the postoperative course and the likelihood of recurrence of symptoms requiring readmission. These findings echo the results of Menberu *et al.*, [19] who identified prolonged hospital stay and shunt failure as independent predictors of mortality and readmission after ventriculoperitoneal shunting. Khan *et al.*, [20] reported that factors such as shunt infections and developmental delays were significantly associated with mortality and adverse quality of life outcomes in long-term follow-up, indirectly implicating delayed care and suboptimal early postoperative management as potential contributors. Mortality within 30 days, although not statistically significant in this study (2.1% early vs. 7.5% delayed, p=0.233), raises important clinical concerns. Holwerda *et al.*, [21] and Vinchon *et al.*, [22] noted that early death following shunt surgery was often linked to late presentation and irreversible neurological injury or sepsis, especially in resource-constrained settings. The Hydrocephalus Clinical Research Network (HCRN) reports have consistently highlighted the relationship between delayed diagnosis and higher mortality, particularly in infants with post-hemorrhagic hydrocephalus [18]. The lower overall mortality rate in this study may be attributable to the exclusion of high-risk cases, such as those with unresected tumors or major systemic comorbidities, or the single-center design which may have ensured more consistent perioperative care.

Symptomatology at presentation played a significant role in determining surgical timing. Children presenting with enlarged head circumference and poor feeding underwent earlier intervention more frequently (46.8% vs. 25.0%, p=0.036; and 55.3% vs. 32.5%, p=0.033, respectively), whereas seizures were more commonly observed in delayed cases (6.4% vs. 25.0%, p=0.015). These findings are supported by observations from Leijser *et al.*, [15] who noted that delayed treatment in infants with post-hemorrhagic ventricular dilation often led to progression of symptoms such as seizures and developmental regression. The timely recognition of macrocephaly and feeding difficulty, often by caregivers or primary pediatricians, thus serves as a critical determinant in expediting neurosurgical referral.

Etiologically, this study reflected a heterogeneous mix, with congenital hydrocephalus, spinal dysraphism, and tumor-related causes being the most common. No statistically significant difference in etiology between early and delayed groups was observed (p=0.337). This aligns with the findings of Holwerda *et al.*, [21] who, in the Dutch Quality Registry Neurosurgery (QNRS), reported that the proportion of infants with aqueductal stenosis and spinal dysraphism remained consistent over time, and timing of surgery was more often influenced by access to care and severity at presentation rather than etiology alone.

In terms of surgical procedures, ventriculoperitoneal (VP) shunting remained the dominant modality in both groups (61.7% early vs. 55.0% delayed; p=0.547), consistent with global trends reported by Tamber *et al.*, [23] who noted that despite the increased adoption of endoscopic third ventriculostomy (ETV), shunt surgery still constituted the majority of interventions for hydrocephalus. In the current cohort, ETV and external ventricular drain (EVD) placements were utilized selectively based on anatomical feasibility and clinical urgency, mirroring contemporary neurosurgical practice. Outcome comparison between VP shunt and ETV was not the primary aim of this study and warrants separate evaluation. The median duration of hospitalization, a key health system metric, was significantly shorter among early surgery recipients. Menberu *et al.*, [19] where prolonged hospitalization (>7 days) was associated with increased hazard of mortality in pediatric shunt recipients. The present findings reinforce that earlier intervention may not only benefit individual patient recovery but also reduce bed occupancy and resource utilization, a crucial consideration in high-volume public hospitals in low- and middle-income countries.

Although shunt malfunction (6.4% vs. 17.5%, p=0.105) and shunt infection (6.5% vs. 12.5%, p=0.325) were more common in the delayed group, the differences did not reach statistical significance. These proportions are clinically relevant and consistent with the work of Deininger *et al.*, [24] who reported shunt revision rates of 46.2% and ETV failure rates of 65.2% over 18 months. It is important to note that the current study's 30-day follow-up window may underestimate the true burden of shunt-related complications, which often emerge beyond this period.

Readmission rates within 30 days were significantly higher in the delayed surgery group, indicating a possible association with unresolved or recurrent symptoms following late intervention. This finding is in agreement with the study by Gmeiner *et al.*, [25] which identified the number of shunt operations and postoperative complications, including infections and epilepsy, as predictors of poor functional outcomes in adults with a history of pediatric hydrocephalus. Early surgical intervention, by potentially preventing deterioration and minimizing systemic complications, may thus reduce the likelihood of early readmission and downstream healthcare burden. Regarding mortality, although the difference did not attain statistical significance, the higher mortality in the delayed group (7.5%) compared to early intervention (2.1%) is consistent with trends reported by Holwerda *et al.*, [21] and Khan *et al.*, [20] who noted that delayed recognition and surgical treatment, often due to socioeconomic constraints and lack of awareness, contributed to poorer survival and developmental outcomes in hydrocephalic children. This suggests that early timing of surgery might act as a surrogate marker of effective referral pathways and preoperative optimization.

Developmental delay as a presenting feature showed a trend toward higher prevalence in the delayed group (40.0% vs. 23.4%; p=0.095), though not statistically significant. This trend corroborates with findings from Tewuerbati *et al.*, [26] where delayed ETV beyond 12 months of age was associated with relatively better neurodevelopmental improvement than procedures performed too early, likely due to pre-existing severe delays in the youngest subgroup. While age at surgery remains an important prognostic factor, the timing relative to symptom onset may be even more critical.

From a public health perspective, these findings emphasize the importance of early recognition and prompt referral of pediatric hydrocephalus cases. Integrating hydrocephalus screening into routine neonatal and infant check-ups, especially in high-risk populations (e.g., preterm infants, children with spina bifida), can facilitate early detection. Community health workers and primary pediatricians can play a pivotal role in identifying subtle early symptoms such as macrocephaly, irritability, or poor feeding, thereby accelerating diagnosis and intervention. The absence of significant differences in surgical modality and etiological distribution suggests that institutional protocols for surgical decision-making were standardized, reducing potential selection bias. External generalizability may be limited, as the study was confined to a single tertiary care center, which may not reflect variability in practices across different healthcare settings.

LIMITATIONS

Several limitations merit consideration. The study design was observational, and though prospective in nature, causality between timing and outcomes cannot be definitively established. Because of documentation issues, we were unable to extract the status on presentation (stable/unstable) for all of the patients. The sample size, while adequately powered for the primary outcomes, may not detect smaller effect sizes for secondary complications like shunt infection or mortality. The follow-up duration was limited to 30 days postoperatively, which precludes assessment of medium- to long-term outcomes such as neurodevelopmental status, shunt revision rates, and quality of life. Socioeconomic variables, parental literacy, and access to follow-up care, important determinants of both timing and outcomes, were not evaluated. The use of non-probability consecutive sampling, although practical, introduces potential selection bias and may affect the representativeness of the cohort.

CONCLUSION

This study demonstrated that early surgical intervention in pediatric hydrocephalus is significantly associated with shorter hospitalization and relatively lower early readmission rates, and potentially associated with fewer complications and mortality. Future multicentric studies with larger sample sizes and longer follow-up periods are warranted to confirm these associations and evaluate the long-term neurodevelopmental impact of timing of surgical intervention in children with hydrocephalus.

ABBREVIATIONS

CSF: Cerebrospinal Fluid.

ETV: Endoscopic Third Ventriculostomy.

EVD: External Ventricular Drain.

HCRN: Hydrocephalus Clinical Research Network.

IQR: Interquartile Range.

SD: Standard Deviation.

VP: Ventriculoperitoneal.

AUTHORS' CONTRIBUTION

Shakeel Ahmed: Conceptualization, Study Design, Writing Draft.

Shoaib Saleem Khan: Study Design, Critical review and revision the manuscript, Final approval, final proof to be published.

Syed Zahid Hussain Shah and **Muhammad Ali Waqas**: Writing Draft, Final approval, final proof to be published.

Ubaid Ullah and **Zeeshan Karim**: Methodology, Data analysis and interpretation, Final approval, final proof to be published.

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Declared none.

ETHICAL DECLARATIONS

Data Availability Statement

Data will be available from the corresponding author upon a reasonable request

Ethical Approval

The study was commenced with the approval of Institutional Review Board bearing letter number 777 dated 10-04-2025.

Consent to Participate

Not applicable as the study was retrospective in nature.

Consent for Publication

All authors give consent for the publication of this work.

Conflict of Interest

Declared none.

Competing Interest/Funding

Declared none.

Use of AI-Assisted Technologies

AI based language editing was done with the aim of improvising English grammar. AI tools were not utilized in research, writing and analysis of this manuscript except for language editing and grammar correction.

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